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## **Effects of the International Boundary Pedestrian Fence in the Vicinity of Lukeville, Arizona, on Drainage Systems and Infrastructure, Organ Pipe Cactus National Monument, Arizona**

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On July 12, 2008, a summer storm delivered 1–2 inches of rain in about 1.5 hours in the south-central portion of Organ Pipe Cactus National Monument (OPCNM). The flash flooding that ensued tested the ability of the newly constructed pedestrian fence along the U.S./Mexico border to accommodate flood flows. The purpose of this report is to document the July 12 storm event, the performance of the pedestrian fence during the flash flood, the effects of the flood on floodplains and channel morphology of south-flowing drainage systems of OPCNM, and the implications for infrastructure maintenance.

### **Background**

The pedestrian fence in the vicinity of Lukeville, Arizona, is 5.2 miles long. It was completed during the spring and summer of 2008. The fence is located within the 60-ft strip of land adjacent to the international boundary known as the 'Roosevelt Reserve,' set aside for public highways by presidential proclamation in 1907. The fence is located several feet north of the existing vehicle barrier, which is several feet north of the international boundary. Adjacent to the pedestrian fence is a dirt patrol road about 45 feet wide that was constructed as part of the pedestrian fence project.

The U.S. Army Corps of Engineers (USACE), in cooperation with the U.S. Department of Homeland Security (DHS), designed the pedestrian fence. A typical fence section is 15 feet tall and is composed of wire mesh panels (Figure 1).



Figure 1. Close-up view of wire mesh on a typical fence panel.

Panels at drainage crossings have grates that were designed to accommodate a flood event (Figure 2). Grate openings are 6-inches (in) high and 24-in wide, with 1-in by 3-in bars.



Figure 2. Fence panels at drainage crossings (above) have wire mesh above larger grate openings intended to accommodate flood flows.

### **Summer Thunderstorms and the 12 July 2008 Storm Event**

The area experiences two annual rainfall periods that, in part, define the Sonoran Desert. The winter season is driven by westerly or northwesterly winds bringing moisture from the Pacific Ocean. Winter storms typically occur between November to April, and are gentle rains that rarely cause flooding. The Arizona or Mexican monsoon typically lasts from July to September in southwestern Arizona. The summer rainy season is driven by southerly or southeasterly winds that bring moisture northward from the Pacific Ocean and the Gulf of Mexico into the desert southwest. Extreme surface heating, combined with the moist air, powers monsoon thunderstorms. These violent storms are often accompanied by strong winds, lightning and flash flooding. Summer thunderstorms are the regional flood source (USGS 1999). On July 12 in the late afternoon, a monsoon thunderstorm occurred over south-central OPCNM. The radar rainfall estimate for that day from the National Oceanic and Atmospheric Administration (NOAA) shows the thunderstorm centered north of Lukeville, in the vicinity of the OPCNM headquarters (Figure 3). The map shows a very small area receiving rain in excess of 2.5 inches (in red, Figure 3).

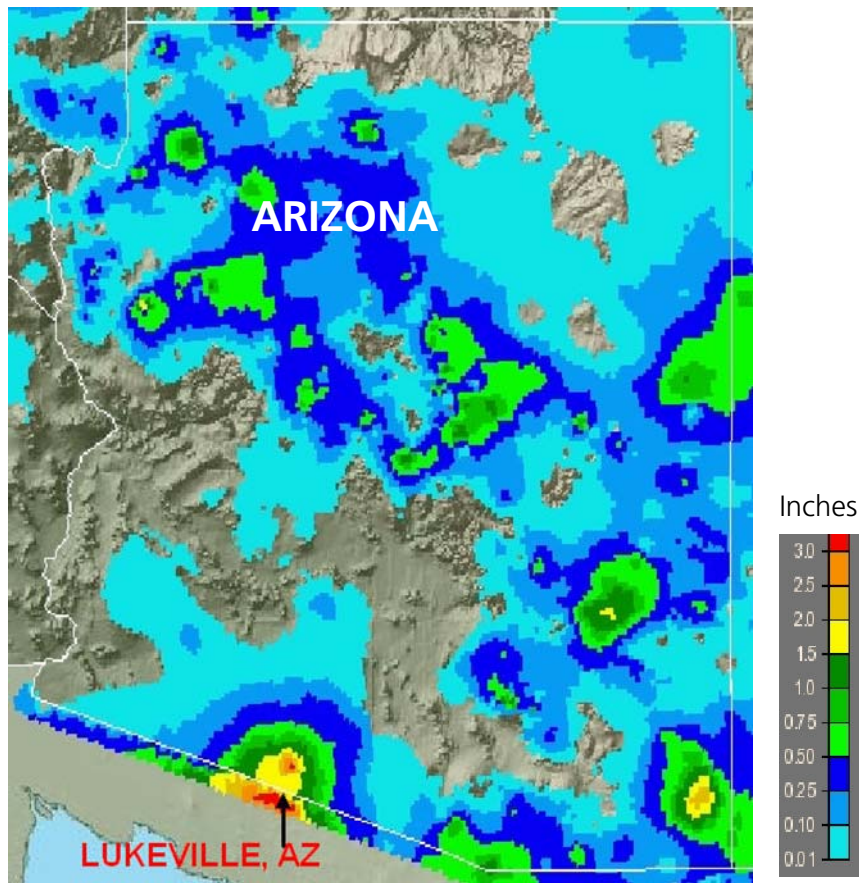


Figure 3. The radar rainfall estimate (in inches) for a 24-hour period from 0500 Mountain Standard Time (MST) July 12 to 0500 MST July 13, 2008, Arizona (NOAA, 18 July 2008). Data is truncated just south of the international boundary.

A different radar rainfall estimate map for the 6-day period July 9 to July 15 shows that monsoonal storms of the magnitude of the July 12 storm are a widespread and normal occurrence across southern Arizona (Figure 4) (NWS, July 15, 2008). At the headquarters climate station, light rain occurred on July 9 and July 10 as well as the heavy rain of July 12. The cumulative total of these rains is shown on Figure 4.

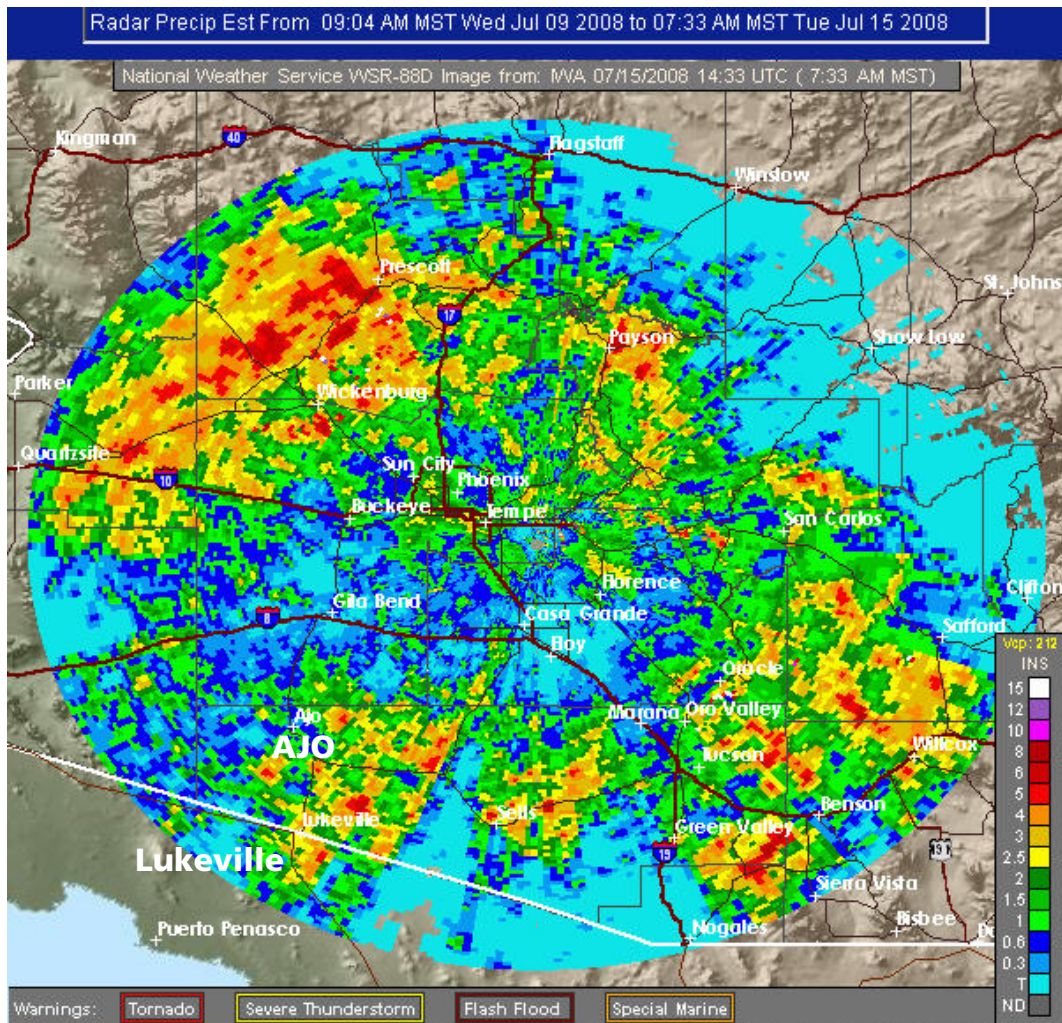


Figure 4. Regional radar precipitation estimates for 9:04am MST July 9, to 7:33am MST July 15, 2008 (NWS, 15 July 2008).

Typical of monsoon thunderstorms, the rainfall event of July 12 was intense and brief. Weather instrumentation near OPCNM headquarters recorded 1.99 inches of rain in about 1.5 hours. This climate station is part of the National Atmospheric Deposition Program (NADP) and is operated by the NPS. A few miles south of headquarters, another rain gauge recorded 1.28 inches of rain in about one hour and 45 minutes, or 0.71 inch per hour. Rainfall at this site, located about 1.5 miles west-northwest of Lukeville, was measured by a tipping bucket with Hobo recorder. Figure 5 shows the locations of the climate station and rainfall gauge.

Summer storm events such as the July 12 storm occur regularly within OPCNM. Based on a 60 year record of daily rainfall at OPCNM headquarters, rainfall events in excess of 2 inches occurred

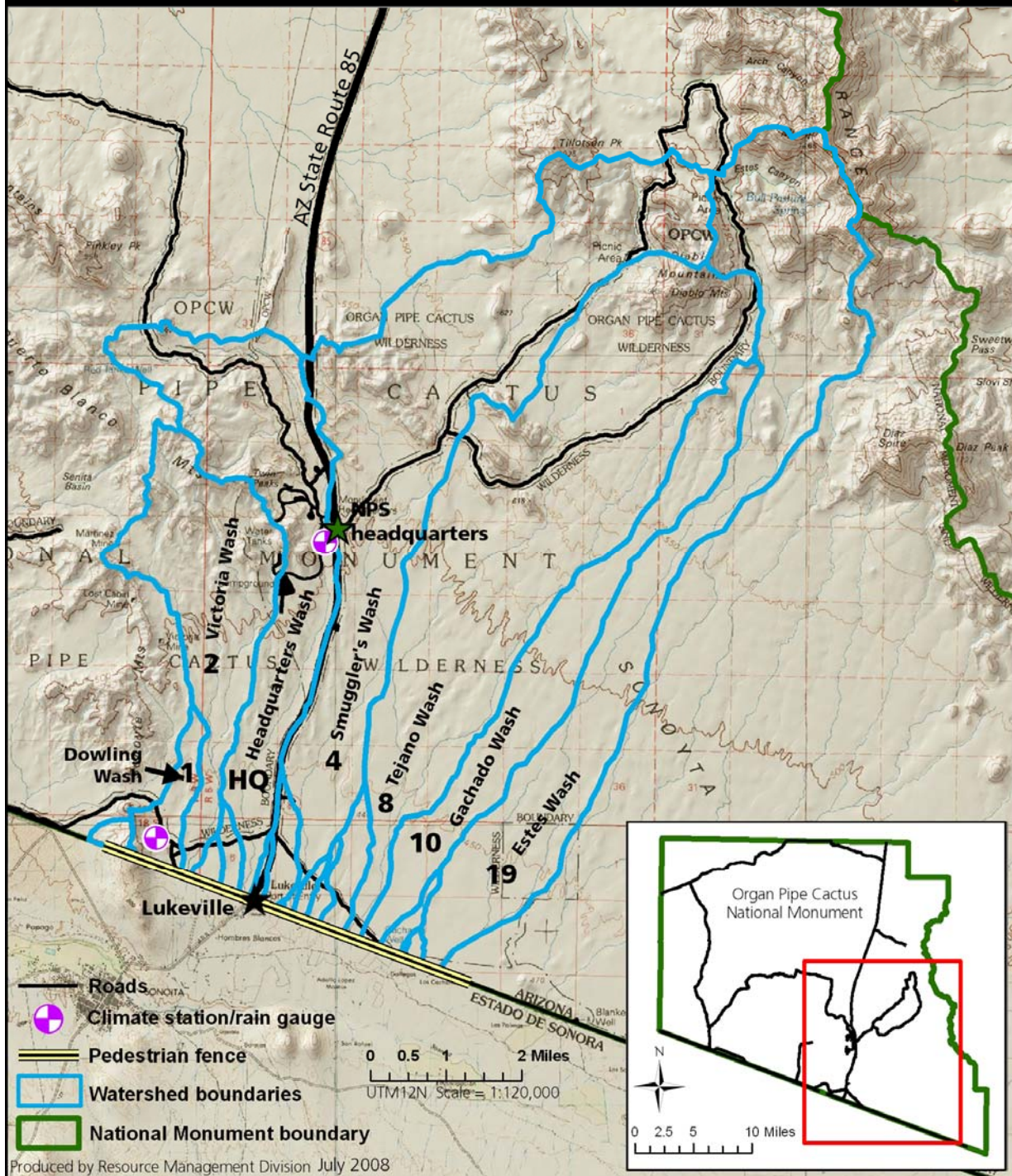


Figure 5. Extent of watersheds draining into Mexico and crossing the pedestrian fence. NPS drainage numbers and names are also listed in Table 1. The drainage area numbers and sizes calculated by OPCNM are different from those used in the hydrologic analysis (USACE/Kiewit 2008a).

12 times, or once every five years. Events between 1.50 – 1.99 inches occurred about once every 3 years, and events between 1.0 – 1.49 inches occurred nearly every year.

The probability that flash flooding will occur due to a monsoonal storm event in the Sonoran Desert is determined by many factors, including the total amount of rainfall, the rate of rainfall (intensity), extent of the storm, the size of the affected watersheds, how much of the area of each drainage area receives rain, and soil saturation preceding the event.

Nearly all drainages crossing the international boundary at the pedestrian fence flow from north to south. The seven largest drainage basins range in size from nearly 1 square mile (sq mi) to over 16 sq mi (Table 1). Drainage areas as determined by OPCNM (Table 1) were derived from an accurate GIS database and were different than estimates in the drainage report (USACE 2008a, p15-16). The latter estimates for Estes and Victoria Wash were significantly underestimated.

The headwaters of Smugglers, Tezano, Gachado, and Estes drainages are located in the Diablo/Ajo Mountains complex. These higher-elevation headwaters located on the eastern side of OPCNM—including Mount Ajo (4,808 ft), the highest point in the Ajo Mountains—typically receive more rainfall during the monsoon than lower-elevation sites (Holm & Conner 2006). The Victoria, Dowling and Headquarters drainage basins have headwaters located in the Puerto Blanco Mountains.

Table 1. The names of drainages crossing the international boundary at the pedestrian fence and the extent of the watersheds above the pedestrian fence.

Drainage Name	NPS Drainage Number	USACE/Kiewit Drainage Number	Drainage Area Estimate (acres)	
			NPS	Kiewit
Tezano Wash	8	E16	10,500	9,384
Smugglers Wash	4	E8	9,548	9,491
Estes Wash	19	E31	7,988	3,741
Headquarters Wash	HQ	W1	4,938	4,754
Victoria Wash	2	W13	3,613	2,839
Gachado Wash	10	E20	3,464	3,419
Dowling Wash	1	W17	593	591

## Fence Design and Performance Criteria

Fence design addressed security performance criteria as well as those relating to hydrology. The following discussion addresses only the design and performance criteria that relate to hydrology.

OPCNM's early concerns about the effect of the pedestrian fence on floodwaters, floodplains, ecosystem function and infrastructure were based on first-hand knowledge of flash flooding and its frequency at OPCNM. Additionally, the vehicle barrier has afforded NPS staff the opportunity to observe how this very porous structure can cause scour and collect debris during a flood event. During scoping meetings and in comments on the draft Environmental Assessment (EA) for the pedestrian fence project (Baiza, *in litt.*, 9 October 2007, USDHA 2007a, USDHS 2007b, Kiewit 2007, *et al.*), OPCNM expressed concerns that:

- The fence would impede the conveyance of floodwaters across the international boundary.
- Debris carried by flash floods would be trapped by the fence, resulting in impeded flow and clean-up issues.
- Backwater pooling would occur due to impeded flow.
- Lateral flow due to backwater pooling would cause environmental damage as well as damage to patrol roads.
- Significant increase in surface water depths (or rise in water elevation) would occur as a result of impeded flow, causing adverse affects on downstream and upstream resources and infrastructure in OPCNM and Mexico.

Addressing OPCNM's concerns, the Final Environmental Assessment (FEA) and Finding of No Significant Impact (FONSI) stated that, in addition to security criteria, the fence would "...not impede the natural flow of water" (U.S. Border Patrol 2007a). It would be "...designed and constructed to ensure proper conveyance of floodwaters and to eliminate the potential to cause backwater flooding on either side of the U.S.-Mexico border" (U.S. Border Patrol 2007a). Further, Customs and Border Protection (CBP) "...will remove debris from the fence within washes/arroyos immediately after rain events to ensure that no backwater flooding occurs" (U.S. Border Patrol 2007a).

The Department of Homeland Security (DHS), OPCNM, USACE and Kiewit met in December 2007 to discuss how the fence design met the required performance standards. In the meeting handout, Kiewit stated the design would "...permit water and debris to flow freely and not allow

ponding of water on either side of the border” because the drainage crossing grates “...met hydraulic modeling requirements” (Kiewit 2007).

The hydrologic design criteria included in the final drainage report (USACE 2008a) were as follows:

- Rise in water elevation due to the fence for a 100-year frequency event would be limited to 6 inches in rural areas.
- Design would consider and protect against scour or long-term degradation at or downstream of the fence location.
- Design would protect against ponded water along the fence.

The drainage report stated that the final fence design satisfied all performance criteria (USACE 2008a).

The USACE/Kiewit based the fence design on a hydrologic analysis that used a 100-year storm as the base storm for determining peak discharge in all drainage basins (USACE 2008a). Two methods were used to determine the 100-year water surface elevations. For drainage areas greater than 10 square miles the 100-year water surface elevations were determined by using equations recommended by the U.S. Geological Service (USGS), even though the USGS advised that the method is not applicable at average elevations below 1,730 feet. (USACE 2008a, USGS 1999). The USGS method for estimating peak discharges from rural streams uses four variables: drainage area (in square miles), average annual precipitation, average basin elevation, and average annual evaporation (USGS 1999). Drainage areas were calculated using a GIS dataset of unknown source, rather than the more accurate OPCNM dataset. USACE/Kiewit’s final calculations for 100-year water surface elevations included considerations given to elevation rise due to the fence posts and grates.

For drainage areas less than 10 square miles, the Natural Resource Conservation Service ‘curve number method’ was used to estimate discharge (USACE 2008a). USACE/Kiewit used the NOAA Atlas 14 to determine precipitation frequency estimate for the project (Bonnin et al. 2006). Atlas 14 for the Ajo, Arizona, area predicts that a storm lasting 1.5 hours with a rainfall intensity of 0.71 inches per hour would occur once every 5 years (based on a partial duration series). Hourly rainfall data from the headquarters climate station confirms a slightly more frequency occurrence (once every 3 years).

### **Performance of the Pedestrian Fence**

This section of the report compares the performance standards set by the FONSI (USBP 2008) and those set by the final drainage report (USACE 2008a) with the actual performance of the fence, as documented by OPCNM. As the USBP performance standards are different from the USACE standards, each will be addressed separately.

*FONSI Standard: The pedestrian fence would "...not impede the natural flow of water" and would allow "...proper conveyance of floodwaters." It would "...eliminate the potential to cause backwater flooding on either side of the U.S.-Mexico border."*

The pedestrian fence impeded the natural flow of water and did not properly convey floodwaters during the July 12 storm. Mainstem drainage channels contained flood flows until reaching the proximity of the pedestrian fence. Debris blockages formed at the upstream side of the fence, restricting water flow and causing significant water elevation rise (Figure 6). The foundation wall of the pedestrian fence stopped subsurface sediment flow, which added to the water elevation rise. Backwater flooding occurred in most washes.



Figure 6. At this drainage crossing west of Lukeville, debris filled most of the length of the drainage grate, causing backwater pooling of 1-2 feet depth. Photograph was taken on July 15, 2006.

*FONSI Standard: Flood debris would be removed "...immediately after rain events to ensure that no backwater flooding occurs."*

Removing debris after a flood is ineffectual at stopping backwater flooding while a flash flood is occurring. Backwater flooding occurs during a flood. Removing debris after a flood will reduce the pooling that would take place during the next flood, compared with leaving the debris in place.

*USACE Performance Standard: Rise in water elevation due to the fence for a 100-year frequency event would be limited to 6 inches in rural areas.*

The storm of July 12 has a return frequency of about once every three years (OPCNM data), or once every five years according to NOAA (2006, partial duration series). According to the design criteria, the fence should not have caused the extensive significant water elevation rise, backwater pooling, or lateral flows from a relatively frequent storm event.

Floodwaters at the pedestrian fence were several feet deep in all the drainages listed in Table 1 as well as in a number of moderate-sized drainages. Since floodwaters were contained within natural channels except at the pedestrian fence, we can deduce that the fence caused a significant portion of the rise. The foundation wall likely contributed to backwater pooling by stopping subsurface flows, adding to water elevation rise.

During the July 12 event, water elevations at nearly all major drainages crossed by the fence rose so significantly that backwater pooling occurred and floodwaters flowed laterally (east-west or west-east) along the fence. Among the more significant lateral flow events were:

- Victoria Wash, with a drainage area of 5.6 square miles, rose against the pedestrian fence and flowed over 1,100 feet to the west into a minor channel. Fine sediment deposits on the fence between the two washes reached a height of 1-2 feet. Where the main channel crossed the fence, the high water mark was about 7 feet above the foundation wall of the fence (Figure 7). It is uncertain how much of this rise was due to the fence.
- Smugglers' Wash, with a watershed of nearly 15 square miles, left its channel at the pedestrian fence and flowed more than 500 feet to the east. It discharged into a channel that normally drains a 0.15 square mile basin.



Figure 7. The floodwaters of Victoria Wash (W13) were blocked by debris and rose to a depth of about 7 feet.

About 2 feet of coarse debris were deposited against the fence (upper photo, July 14, 2008). A band of fine sediment marks the high water line at flood stage.



The same site as above, after flood debris was cleared (middle photo, July 16, 2008). Distance from the foundation wall of the fence to the high water line is over 7 feet.



Figure 8 (left). Impounded by the pedestrian fence, floodwaters from Headquarters Wash, which normally flows from north to south, flowed to the east along the fence and into the Mexican Port of Entry in Sonoyta, Sonora. The white SUV is southbound into Mexico.

- Gachado Wash, which drains an area of 5.4 square miles, also flowed over 300 feet to the west into another channel. Coarse woody debris was deposited on the patrol road as far as 400 feet west of Gachado Wash. Wash bed sands were deposited on the road surface between these two drainage channels, indicating that the velocity of floodwater was sufficient to carry sand particles.
- Estes Wash travelled more than 500 feet to the west along the pedestrian fence foundation. Prior to the construction of the pedestrian fence, lateral flow of floodwaters along the international boundary had never been documented in the project area.
- Headquarters Wash flowed over 200 feet to the east along the pedestrian fence and through the international port of entry. It caused flood damage to private property, government offices and commercial businesses in Lukeville, Arizona, and Sonoyta, Sonora, Mexico (Figure 8).

Backwater pooling against the fence caused sedimentation to occur, at least in stream reaches near the fence. Sedimentation occurs when floodwater velocity decreases or is stopped by an impoundment. Evidence of sedimentation due to the pedestrian fence would include the presence of fine sediments in stream reaches normally having only sand and gravel. The flood of July 12 deposited a thick layer of fine sediments on the lower reaches of major washes. We could not determine the depth of sediments deposited on the patrol road because on July 16 they were either covered with debris or they had been removed prior to our visit.

Fine sediment deposits were documented in stream reaches above the patrol road. Accumulation of fine sediments in these stream reaches will, over the long term, change the hydrology of these drainage systems upstream. Downstream from the fence in Mexico, drainages will be affected eventually by the decrease in sedimentation.

Notable fine sediment deposits were documented in Tejano Wash (Figure 9), Estes Wash, Dowling Wash, Victoria Wash, and Smugglers' Wash upstream from the patrol road on July 16, 2008. These deposits were also observed at Gachado and Headquarters washes, but the observation was not photographically recorded, as repeat photography did not occur at this sites.



Figure 9. Prior to fence construction (above), the bed of Tejano Wash (E16) was composed of coarse sand and gravel (NPS photo, 9 July 2008). After the flood (below), flood debris can be seen in the foreground of the same scene, and a new deposit of fine sediment can be seen in the midground (NPS photo, 16 July 2008).



*USACE Performance Standard: Design would consider and protect against scour or long-term degradation at or downstream of the fence location.*

Considerable scour occurred downstream from the pedestrian fence. Some of this scour can be attributed to the pedestrian fence, while some sites will require additional time and study to determine if the pedestrian fence accelerated scour or not.

Scour that can be attributed to the pedestrian fence includes areas where lateral flows or backwater pools crossed the fence outside of natural drainages. Scour also occurred at the upstream side of the foundation wall (Figure 10).



Figure 10. Floodwaters flowed laterally along the pedestrian fence, causing scour at the foundation wall and erosion of the patrol road in places. (NPS wash 17, east of Lukeville, July 16, 2008).

A water elevation rise of up to 7 feet at the pedestrian fence caused significant scour at the foundation wall and vehicle barrier on the downstream side. Erosion control fabric was displaced and in most large wash crossings is no longer functional (Figure 11).



Figure 11. Left: Downstream from the pedestrian fence, a 7-ft tall cascade of water caused downstream scour at Victoria Wash (NPS photo July 16, 2008). A Kiewit photo taken before construction (USACE 2008a) shows no scour at this site.

Right: At Estes Wash, floodwaters flowed along the foundation wall on the downstream side, causing scour at the vehicle barrier. At this site, the erosion control fabric remained in place, although exposed.

*USACE Performance Standard: Design would protect against ponded water along the fence.*

We assume this design standard was written to protect against ponded water on the patrol road during and after rainfall events. The design appears to have met this standard for the patrol road. Some ponding did occur, however, in areas upstream from the patrol road where road elevations are above the natural surface elevations, especially where small drainages are impounded by the road or where road berms block runoff. During the next few decades, vegetation change will occur in those areas along the northern edge of the patrol road that receive and retain runoff.

## Conclusion

Our data and observational information show that the pedestrian fence did not meet the standards set by the FONSI (USBP 2008) or the USACE's hydrologic performance standards (USACE 2008a). As a consequence, natural resources of OPCNM and NPS infrastructure will be impacted, as well as resources and infrastructure on neighboring lands in the U.S. and Mexico. Short- and long-term impacts that are expected due to the pedestrian fence include the following:

- Accelerated scour below the pedestrian fence will damage the structural integrity of the vehicle barrier along the U.S./Mexico boundary unless continued maintenance occurs.
- Floodwaters will flow laterally along the pedestrian fence and on the patrol road. These flows will result in erosion and scour above and below the foundation wall of the fence, including areas hundreds of feet outside existing drainage channels. As a consequence, the need for routine maintenance and repairs of the patrol road and vehicle barrier will increase.
- The patrol road associated with the pedestrian fence will change vegetation in OPCNM by changing rainfall retention or runoff along the northern road edge.
- Riparian vegetation will change in response to increased sedimentation.
- Channel morphology and floodplain function will change over time.
- Channelized waters will begin a gulying process that has the potential to transform land surfaces in the affected watersheds.

We recommend that third-party, objective experts should conduct a review of the performance of the fence with regards to hydrologic criteria. The fence needs to properly convey debris-laden flood flows. Significant pooling, lateral flows and scour should be minimized by improved fence design. The structural integrity of the vehicle barrier needs to be maintained because it continues to play a strategic role in border security and resource protection. Road-edge effects on vegetation should be minimized by better management of berms and road elevations.

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